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N90-20664

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ENGINEERING VISUALIZATION UTILIZING ADVANCED ANIMATION

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INTRODUCTION

Engineering visualization is the use of computer graphics to depict engineering analysis and simulation in visual form from project planning through documentation. Graphics displays let engineers see data represented dynamically which permits the quick evaluation of results. The current state of graphics hardware and software generally allows the creation of two types of 3D graphics. One type features highly-detailed, realistic images that are displayed in non-real-time. The other type permits real-time display, but only for relatively crude graphics. (Real-time for our purposes is defined as the update of a display at a sufficient rate to make the change invisible to the human eye, typically 30 frames per second.) There are simulators capable of producing realistic 3D motion in real-time but their cost can be prohibitive. Animation provides an alternate route to generating realistic 3D graphics which are recorded on video for later playback in real-time. A fully produced video animation has the power to provide the organization, clarity, and attention to detail demanded for the communication of complex engineering concepts.

This paper presents the use of animated video as an engineering visualization tool. The engineering, animation, and videography aspects of animated video production are each discussed. Specific issues include the integration of staffing expertise, hardware, software, and the various production processes. A detailed ex-

planation of the animation process reveals the capabilities of this unique engineering visualization method. Automation of animation and video production processes are covered and future directions are proposed.

EVOLUTION OF ANALYSIS AND SIMULATION VISUALIZATION

Before turning to a discussion of animation and video, it would be helpful to review the evolution of engineering visualization. Some ten to twenty years ago, analysis and simulation results were printed out as pure data. Mountainous stacks of computer paper were produced that required hours to sift through. The engineer could graph the data in two dimensions on graph paper or perhaps have a draftsman illustrate it. The development of plotters eliminated the need to produce these graphics by hand.

Later, as computers grew more sophisticated, it became possible to represent three-dimensional objects using complex data structures. The plotter was immediately employed to produce two-dimensional renderings of the objects. It also became possible to produce static 2D displays of the 3D objects on a CRT. The natural next step was to set the objects in motion. Doing this has proved to be a most challenging task.

A great deal of computing power and memory is required to render a 3D object quickly enough to provide the illusion of motion. The

complexity of the scene being rendered is a major factor in the amount of time required. The result is that a crude representation may move at a satisfactory rate while a realistically detailed image moves too slow in real-time to be of value. Obviously the goal is to produce realistic real-time graphics. Technology today is on the verge of providing such graphics but only at a relatively high cost. The speed and realism of the specialized high-performance simulators is astounding, but so is the price. It is this gap between affordable high-speed systems and realistic real-time display that animation fills so well. Depending on the level of complexity desired, animation may require a great deal of time to generate, but when completed it provides real-time speed via videotape playback.

DEVELOPING AN INTEGRATED APPROACH TO VISUALIZATION

The process of engineering visualization is a complex task. It is made even more difficult when the demands of engineering documentation are added to it. Although engineering simulation, graphics, video, and documentation have all been previously used as stand-alone entities, the integration of them as a full-fledged production tool has just begun. By identifying the staffing expertise required, coordinating that expertise, employing the appropriate hardware and software, and standardizing the processes involved, engineering visualization can simultaneously be integrated and simplified (Figure 1). This type of approach was used in the development of the Mars Rover

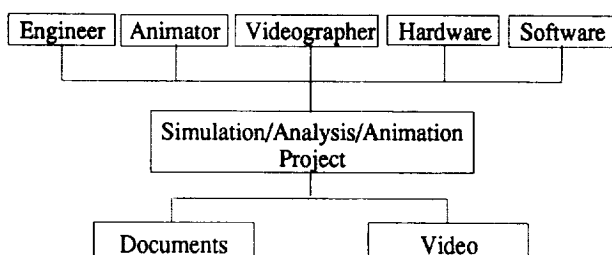


Figure 1 - Project Integration Overview

Sample Return Mission video shown at the 1989 Graphics Technology in Space Applications conference video show.

DIVERSITY OF EXPERTISE REQUIRED

The staffing expertise required for engineering visualization using animation consists of three general categories: engineering, animation, and videography (see Table I). Although the topic is "engineering" visualization, the animation and videography staff provide unique expertise and talent that cannot be overlooked.

Table I -Diversity of Expertise Required

Engineering:	Animation:	Videography:
Aerospace Sciences Analysis Simulation Hardware Design Software Dev. Communications User Interfaces Graphics Fractal Geometry	Artistic Creativity Visual Composition Storyboarding Computers Model Building Motion Hierarchy Motion Generation Kinematic Timing Rendering Image Manipulation Paint Systems Digitization	(Video) Single-frame Record Editing Operations Switching Special Effects Units Character Generators LaserDiscs (Audio) Scriptwriting Announcing Recording Editing Music Sound Effects Sound Mixing Digital Processing

Engineering expertise can be broken down into two dissimilar disciplines. The first represents the "line organization" engineering staff that contributes technical direction to the effort. The areas of expertise of this group include those traditionally associated with aerospace engineering: sciences, research, design, analysis, and simulation. The second consists of software engineering personnel. They provide direct support in the form of system administration, graphics programming, and software development.

The animation staff, besides operating the animation software, are responsible for adding the realism and presentation value to the animation. They collaborate with both the line engi-

neer and the videography staff to produce a storyboard which summarizes the visual content of the animation. They then contribute a variety of skills and artistic talents including visual composition, image manipulation, kinematic timing, model building and other components vital to the creation of an animation.

Videography, like engineering, involves two separate areas of expertise. One area includes the creative skills and technical knowledge necessary to produce the audio soundtrack. The scriptwriter must know how to write for a speaker. The announcer must be able to annunciate the text and must be trained to avoid popping and hissing speech. Audio technicians must understand an array of recording, editing, and mixing equipment. Video is the other, and more obvious area, of videography expertise required. The hardware intensive nature of video production requires considerable technical knowledge. Technical savvy must be combined with artistic and creative talents to produce an effective video presentation. The videography staff also works closely with the animation staff providing both technical and creative direction.

ELEMENTS OF ANIMATED VIDEO PRODUCTION

The process of creating an animated video production occurs in four major steps. Planning is the first step. It includes the development of a script, a storyboard, and a shot list. The script is a written narrative for the presentation that is carefully timed to coincide with the corresponding images on the screen. The storyboard is a series of thumbnail sketches of the images themselves. The shot list is a description of the images with details about length and other technical issues. These are developed together by the engineering, animation, and videography staffs and provide a basic plan for the final production. All are used to guide the other steps of the process. The second step is the generation of the animation. The animation staff uses the storyboard and the shot list to generate the

needed sequences. When the animation is completed it is recorded on videotape or other video media. The third step is the development of an audio track. The script is recorded and edited to the proper length. Music and sound effects are then added. When the audio track is completed, it is recorded onto the sound channel of a videotape or disc. The animation and audio track development steps may occur simultaneously if planning has been thorough. The final step is video post-production. The animation and audio (now both recorded on video media) must be edited together and title and credit sequences added.

The transmission of knowledge and information from the engineering workstation to the video presentation is made possible by animation. What distinguishes animation from a simple recording of images from the workstation? Single frame recording to video provides real-time playback of both, but animation adds valuable visual realism in a variety of ways. This is revealed through a more detailed examination of the animation process (Figure 2). This examination is based on the assumption

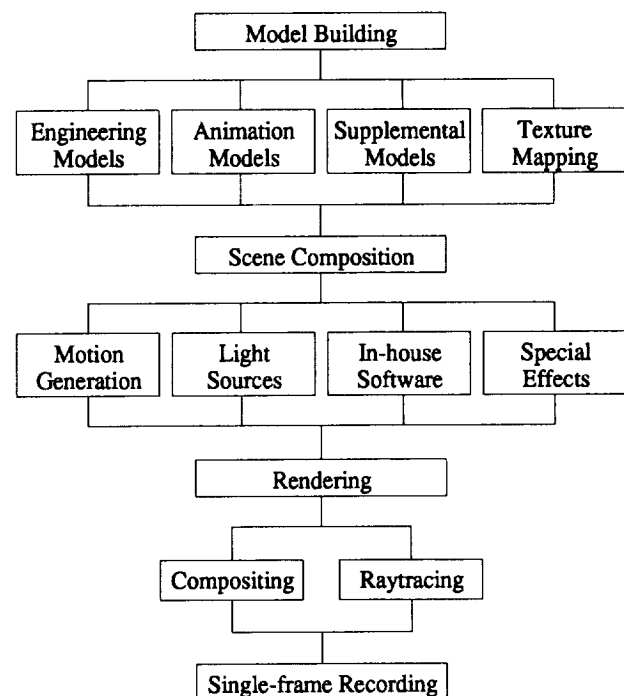


Figure 2 - Elements of Animation

that the planning phase has been completed and that a storyboard, shot list, and script have thus been developed.

Model Building

Model building is one of the first activities required in the animation process. There are many levels of 3D modeling. The highest level includes the models familiar to most engineers. The precise, technically complete, 3D models used in engineering are invaluable. The detail of these models is demanded by the rigorous requirements of design and analysis. At the other end of the modeling spectrum are crude, inaccurate representations of objects valuable for only the most cursory evaluation of size and motion. The advantage to these latter models is the speed with which they can be manipulated. Animation requires the complete redrawing of every model on the screen thirty times to generate just one second of motion. The more detail a model has, the more time is required to draw it. The need for detail must then be weighed against the amount of time available to produce an animation. Animation models are developed with an awareness of this fact. The optimal relationship between speed and detail is usually found by using models in which unseen mechanical details are omitted. Very close attention is paid to the external visual details but the unseen inner workings are ignored. If focus on a particular mechanical feature is desired, it can be modeled and added at the appropriate point in the sequence. Millions of unnecessary calculations can be eliminated by the use of these simpler models. At the same time, to the viewer, the model is physically complete. The animator may develop supplemental models to represent scenery and other items.

Texture Mapping

Once models have been developed, their realism can be enhanced by a technique called texture mapping. Texture mapping is the process of generating a 2D image which is then

mapped onto the surface of a 3D model. There are several forms of texture mapping and each form excels in a particular situation.

The simplest type of texture mapping is where a digitizer or paint system image is mapped directly onto the surface of a model. This is highly effective for producing foregrounds and backgrounds, and for adding logos, flags, and unusual surfaces to models. In the case of a foreground or background, the image is simply mapped onto flat or deformed surfaces and placed in the scene. Alternately, an image can be wrapped around a model to simulate the appearance of metal or some other material. In the Mars Rover video, this type of mapping was used extensively in the Titan launch sequence and to create the rocky Mars surface.

A specialized type of texture mapping called bump mapping can be used to simulate a relief surface where none exists. The image is mapped onto an object but no color is used. Instead, bump mapping uses the luminance values of the 2D image to determine how to deflect light falling on the object. Luminance is a measure of the black, white, and grey values contained in the image.

Similar to bump mapping is transparency mapping. Like bump mapping it uses only the luminance values of the 2D image. The difference is that transparency mapping uses these values to determine a level of transparency for the surface onto which the image is mapped. White will cause the surface to be opaque, black will cause it to be transparent.

One other useful type of texture mapping is reflection mapping. Reflection mapping retains the 2D image's color and maps it onto the surface of an object. What makes reflection mapping special is how the map image is generated. The animation software is instructed to render a view of the scene from the location and orientation of the surface that is to show the reflection. This view is used to generate the map image which may then be sized and distorted as

necessary to cover the surface.

Motion Generation

The next step in creating the animation is the actual generation of movement. One of the most common methods for accomplishing this is called keyframe animation. Keyframe animation allows the animator to define frames depicting the starting and ending positions for objects in the scene. The number of frames that are to occur between the starting and ending frame (at a rate of 30 frames per second) are then specified. The computer interpolates the position of all objects for each of the intermediate frames. Transformations along the objects' X, Y, and Z axes can be used to create non-linear paths. Translation, rotation, scaling, and skewing are some of the many attributes that can be specified singly or in combination to cause transformations. If connecting parts of an object must move relative to one another, this may be depicted using a technique called hierarchical motion. Hierarchical motion involves the assignment of relationships between different parts of a model. The main section of a model may be designated as the "parent" and its appendages as "offspring." The action of the connecting joints may also be defined with regard to limiting angles and rotational axes. The result is that when the parent moves, the offspring follow in a way defined by these relationships. This can make the simulation of realistic movement much easier to accomplish. Ultimately, the animator must use these techniques to create motion which is realistic and compositionally logical to the viewer, but also technically accurate in the eyes of the engineer.

Lighting

Convincing motion of realistically designed models goes a long way in creating an authentic animation. There are other compositional elements that must also be considered. The animation software provides an environment somewhat analogous to a windowless room: if no lights are turned on, nothing can be seen.

The placement of light sources then becomes an issue. In the simulation of aerospace operations, it might seem logical to have only one light source representing the sun. In truth however, other sources of light must be considered. Light reflected from the Earth, the Moon, or other bodies can brighten unlit areas. Small man-made sources of light may also need to be simulated. Several different types of light sources are usually available in the animation software. Flood, spot, unidirectional, and omnidirectional sources are common and may be used to create specular, diffuse, and ambient light. Color can often be added to light sources as well. The selection and placement of light sources generally follows the same principles used in photographic or motion picture lighting.

Special Effects

The presence of light would also imply the presence of shadows. Shadows are not an ordinary by-product of a lighted object in a computer however. The location and darkness of shadows must be computed based on the location and characteristics of the light sources and the shape and location of the objects in the scene. It is a complex problem with a computationally intense solution. Implementation of shadowing usually results in a significant increase in the amount of time required to render each frame but is justified by a dramatic increase in image realism. The advent of shadowing options is a fairly recent development in animation software. At the current stage of hardware and software development, shadowing is still considered a "special effect."

Other capabilities which fall under the category of special effects include transparency and distortion of objects. While a transparency map can be used to give an object a transparent quality, variations in degree of transparency are not a standard feature. Such an effect can be used to reveal hidden structure within an object. An example of this appears in the canister transfer sequence of the Mars Rover Sample

Return Mission video. There is no standard method of producing variable transparency among those animation packages that support it. It is achieved in one package by entering a transparency factor for each individual frame in which the object's surface appears. This can be a tedious process but the result provides a very effective way to present technical detail.

Distortion of objects is a special effect that is useful for depicting non-rigid objects. Plastic, rubber, and textile objects are likely candidates for the use of distortion effects. Distortion is still the subject of much research and, like variable transparency, is achieved by a number of methods. Metamorphic distortion is available in some animation packages. This method allows a model's shape to be altered from one key frame to the next. The animation software then interpolates between the shapes in the same way that it interpolates an object's motion. Another form of distortion permits an object to be stretched along one of its three axes while it is compressed along the other two. This is sometimes referred to as volume distortion. Skew is a diagonal distortion of a model along two of its axes. These techniques can sometimes be used in combination with one another. This can be very effective at adding naturalism to the motion of flexible objects.

In-House Software Development

Most of the object manipulation methods discussed thus far are made possible by the standard or advanced features of commercially available animation packages. Animation of certain types of objects or effects are not currently within the capabilities of these packages however. The use of in-house graphics programming expertise may be helpful in such cases.

Research was needed in several instances to determine how to simulate various effects for the Mars Rover video. The action of the lander vehicle's parachute filling with air required the development of specialized code. Smoke for

the Titan IVs and the Mars ascent vehicles was initially generated with a complex mathematical algorithm employing Fourier transforms and digital filtering. Another method of producing smoke was subsequently developed using an innovative combination of polygon distortion and moving bump maps. Custom software may sometimes be required for the creation of specific types of motion as well. The movement of the rover vehicle across the Martian surface is one example. Each of the six rolling wheels has to maintain surface contact with the irregular terrain yet remain in the correct orientation to the rest of the vehicle. In a more recent project, research was required to convincingly depict dust being stirred and settling back to the ground in a low-gravity environment. Problems like these are of particular interest in aerospace where unusual conditions are so frequently encountered.

Rendering

When all of the image manipulation and motion problems of the animation sequence have been addressed, there remains one more step in the animation process. The animation sequence must be rendered in solid form. Rendering is the computing of the final animation frames using all of the options and effects that have been defined by the animator. Prior to rendering, the animation exists only as a wire-frame representation in the animation software. Texture mapping, lighting, shadows, and other effects are not yet visible. It is in this process where time intensive operations take their toll. A great deal of computing speed, memory, and storage are needed to render even a few seconds of animation. When a high-speed rendering engine is used, a complex frame full of intricate objects, reflections, and shadows may take from four to forty minutes to create. Additional time may be required if certain specialized rendering methods are used. One of these methods is called ray-tracing.

Ray-tracing results in highly realistic animated images. It works by calculating the path of ev-

ery beam of light from each light source to each pixel of each object on the screen and then back to the viewer's eye. It is especially effective when objects have glass or other highly reflective surfaces. Multiple levels of ray-tracing allow an increasing amount of detail but at a great penalty in computing time for each additional level. Ray-traced images have an almost photographic realism.

Compositing is also part of the rendering process and allows layering of separately generated images. This may be used to add background elements to a scene that was generated without them. Compositing reduces the amount of time required to render an image because static background images are rendered only once. Only the moving objects are recalculated for each new frame. This would seem to make compositing highly desirable. Actually a time trade-off takes place because compositing increases the amount of time required to display the completed image. This slows down the recording process. Whether compositing is desirable is determined by evaluating how computing resources may best be allocated between rendering and recording operations. Another way of compositing is available that eliminates the recording time penalty. The use of digital video storage devices and special effects units allows real-time compositing but requires the purchase of more expensive hardware.

Single-frame Recording

As each frame of animation is rendered, it is stored on the computer's mass storage unit, usually a hard disk. It cannot be played back in real-time from an ordinary hard disk however because access time and reconstruction of the display is too slow. Instead, software is used to display each frame individually and to trigger a video recording device to record it via specialized animation-control hardware. Among the devices that may be used for single-frame recording are videotape recorders, optical laserdisc recorders, and digital frame storage

devices. Generally only the high-end, professional-format videotape recorders are capable of recording in single-frame mode. Recording of the frames to video completes the animation step of the animated video production process.

Editing

Editing is the arrangement of raw audio and video into a complete and coherent presentation (Figure 3). Audio editing is the next step of the animated video production process. This step technically begins when the script is written. Scripts are written in a two column format with the spoken text in the right column and a description of the corresponding visual images in the left column. The right column also contains details about music and sound effects and instructions to the audio technician. This format allows each portion of text to be carefully timed to match the correct image. The language of the script must have a narrative flow that sounds natural when spoken aloud. The script is recorded onto multi-track audio tape using a professional announcer. (Untrained speakers find it difficult to eliminate certain extraneous sounds from their speech. These can be very distracting in a recorded soundtrack.)

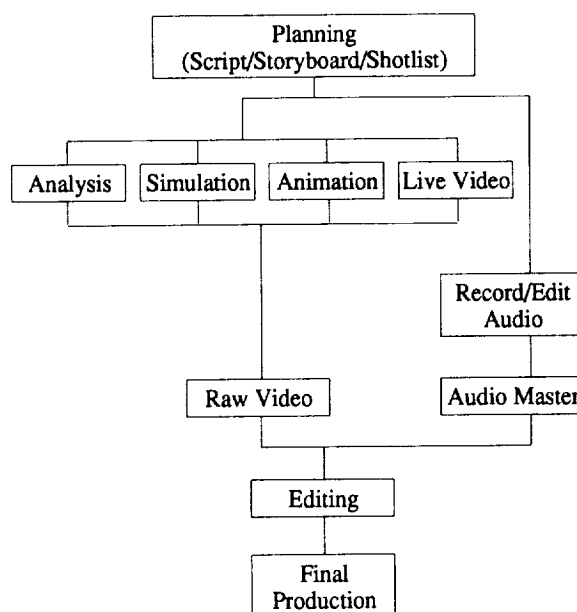


Figure 3 - Video Production Overview

After the script has been recorded, it must be edited to eliminate mistakes and to make it the proper length. Music and sound effects are then generated or selected from a library and added behind the voice on another track. A time code recorded on one track of the tape makes very precise editing possible. The completed soundtrack is referred to as the audio master or the soundtrack master. Because of the timing elements involved, implementing changes in the script after the edit session are very difficult. Usually, re-recording and re-editing of the entire soundtrack is necessary.

When the audio master has been completed, it is transferred to a blank videotape or other video media. The final step in the animated video production process is editing of the raw animation video onto the audio master tape. Live video footage may also be incorporated into the production at this point. Some animated (and live) sequences that have been generated must be slightly longer than the amount of time they are to appear on-screen. Additional footage at the beginning and end of each sequence gives the video editor a place to create transitions between scenes. Cuts, dissolves, and wipes are among the many types of transitions available through modern video editing equipment. The primary tools of a video production facility include character generators, edit controllers, video and audio switchers, special effects units, time base correctors, and video recording devices. These are used to assemble and refine the final video presentation.

Character generators allow the creation of titles and credits. A special effects unit may be used to overlay these onto the video footage or place them on a colored background. Special effects units can also provide the previously mentioned transitions and other manipulation of the video images. Switchers are used to generate dissolves, wipes, upstream and downstream chroma and luminance keying as well as soft and hard-edged transitions via special effects. A video edit controller allows precise editing of the video. A device called a time base correc-

tor may be used to compensate for anomalies in the video signal. Typically, at least two video sources are connected through time base correctors to a video switcher and an edit controller for output to a recording device. Time code is usually recorded on the video media to provide frame-accurate control of the editing process. A standard for time code, developed by the Society of Motion Picture and Television Engineers (SMPTE), is used for most video and audio editing.

In editing the animation video, the soundtrack is the reference for assembling the scenes. This is why integral development of the script, the storyboard, and the shot list is so important in the planning phase. Sound effects must precisely coincide with the corresponding visual action. The narrative description must match exactly what is depicted on the screen. The viewer's interest must be maintained with an accurate, clear, and concise explanation of the concepts being presented. With careful planning and an integrated approach to the animated video process, this can be achieved very effectively.

AUTOMATION OF THE ANIMATED VIDEO PRODUCTION PROCESS

Engineering visualization is still a fairly new concept. Much of its potential remains unrealized because of a lack of automated processing and standard interfaces between and within its various disciplines (Figure 4). Some relationships between engineering, animation, and video exist already, but in each case the development of automation and interfaces has been an isolated process.

Engineering analysis and simulation have utilized 3D computer graphics since the late-1970s. Software and hardware interfaces are plentiful and standards are becoming fairly well established. An entire industry has arisen around the development of CAD/CAE workstations. Networking of computer systems has contributed an element of transparency to the

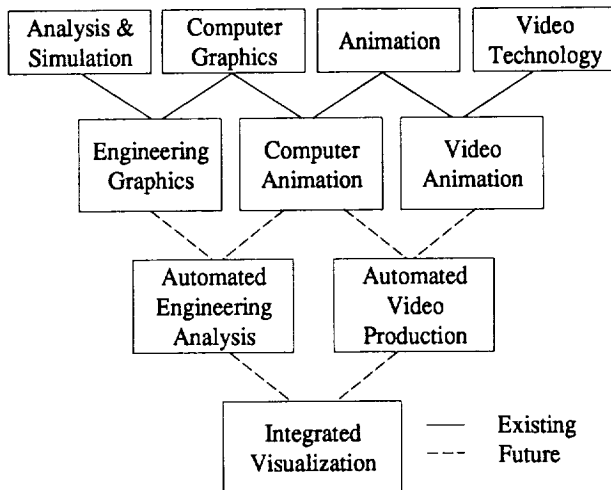


Figure 4 - State of Visualization Technology

interfaces. The Initial Graphics Exchange Specification (IGES) and Computer Graphics Metafile (CGM) are among the many graphics file standards developed for use within this field.

Television standards have been around for several decades and in no way reflect the current state of graphics visualization hardware. Television standards were designed to allow use of compatible analog signal by either black and white or color television sets. Automation of video production is occurring but with few of the benefits of digital technology inherent in the computer industry. One promising new development is a video version of the computer network. The Video Local Area Network (V-LAN) permits the same degree of transportability over video control signals that a computer network allows over data.

The use of 3D computer graphics for animation started in the early 1980s and interfaces and standards for it are just beginning to be defined. Whereas 2D animation was used almost strictly for entertainment and commercial purposes, 3D animation has become a valuable tool in the scientific and engineering world. Although animation is historically associated with film and video, the use of 3D computer graphics to generate animation is requiring unprecedented

computer to video interfaces.

The dissimilarity of hardware is at the root of most problems faced in automating the animated video production process. The engineer's workstation, the animator's workstation, and the videographer's equipment typically have different screen resolutions. In addition, the two workstations usually output red, green, and blue (RGB) signal values at a scan rate of 60 hertz. The videography equipment requires separate color and luminance signals synchronized and interlaced at a scan rate of 30 hertz. Getting an image from one device to the next often requires as much specialized equipment as do the systems themselves. The capabilities, limitations, and compatibility of each individual component must be considered. Automation is made possible only when all of the hardware interfaces are resolved. If this can be accomplished, the next step is the development of automation software.

Rendering and single-frame recording of animation can be automated through software. The development of the V-LAN mentioned earlier provides the capability to control the video production process through software and audio editing can be automated as well. The complexity and speed involved in automating these processes requires fast processors, fast programming languages, and creative and efficient software design.

FUTURE DIRECTIONS

The ultimate expression of automation would be an integrated system designed to facilitate the engineering visualization process from beginning to end. Such systems are yet to be developed but the general direction of the related industries makes their eventual appearance inevitable. Many graphics terminals in use today have the capability to support multiple screen resolutions and to accept a video synchronization signal from an external source. Some can generate their own "sync" for direct output to video. These systems are the first step towards an integrated hardware system. The software

tools are also beginning to appear. Video edit control software that uses the previously mentioned V-LAN is now commercially available. Single-frame recording software is available which drives videotape animation control hardware. Most of the hardware and software on the market now is in its first development generation.

User interfaces for these emerging tools are following the trend towards intuitive operations. Intuitive interfaces reduce the learning curves associated with complex software and, if well designed, can result in faster operations. This will be especially important to the success of integrated systems where different types of users are involved. Consistency between the interfaces for the engineer, the animator, and the videographer will result in a smoother flow of ideas and information and faster production turnaround.

Engineering visualization technology is rapidly advancing. Hardware interfaces and software formats are now being developed which will streamline the process of documenting the engineering process through animation and video. The merging of engineering analysis and simulation, 3D animation, and video is a natural step which will enhance the engineering environment. The NASA Mission Support Directorate's Animation and Video Production Facility hopes that the insight it has gained over several years of integrated efforts may represent a worthwhile contribution to the direction of this effort.

References:

Bentz, Tom, "Computers In Editing," Video Manager, Torrance, CA., Vol. XI, No. 10, October, 1988, pp. 48-50.

Davis, Susan, "The Computer Connection," Video Manager, Torrance, CA., Vol. XI, No. 7, July, 1988, pp. 19-24.

Robertson, Barbara, "Graphics Leaps Into Space," Computer Graphics World, Westford, MA., Vol. 10, No. 8, August, 1988, pp. 44-46, 48.

Robinson, Thomas L., Sabionski, Gunter R., "Visualization Engineering Gives NASA A Window on the Future," Computer Pictures, Clifton, NJ., Vol. 6, No. 3, pp. 60-64.

Schwartz, Howard, "Audio for Video," Video Systems, Overland Park, KS., Vol. 14, No. 8, August, 1988, pp. 24-25.